Hydraulic Energy
Technology Branch
Energy Mines and Resources Canada

Syphon Hydro Research and Development 1984 - 1989

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1 - Introduction

The use of syphons date back to 1500 BC when the Greeks and Romans used them to convey drinking water over high terrain. Modern day syphons consist of large installations for both water supply and irrigation schemes and, more recently, smaller installations for hydropower development.

The recent interest in syphon hydro developments is clearly evident from Figure 1, which gives a list of syphon hydro installations that has been compiled during earlier phases of this study. Current turbines and penstock design technology coupled with the highly competitive nature of power development, warrant the serious consideration of syphons as an alternative to the conventional hydropower structures. Where a dam or similar structure exists, the potential for use of syphons is obvious. The elimination of intake gates for dewatering the units for inspection coupled with the minimal impact on the existing forebay structures, makes syphon hydro an attractive proposition.

Acres International Limited (Acres) has had the opportunity to participate in (or conduct) six syphon hydro studies, two in the US and four in Canada. These studies included the review and investigation of small syphon hydro installations with the objective of understanding more fully the engineering design concept characteristics required to develop a site. One of the overall goals of the study is to achieve a generic design of installations which would be an ideal alternative to using hydrocarbon-fueled power systems in small communities. Syphon hydro installations can be fully automated and operated unattended. The following sections summarize the research work on this topic that has been undertaken by Acres since 1984.

No.	Project Name	Syphon Lift (m)	Flow ($m^3/_s$)	Net Head (m)	Power (kW)
1	Wasdell Falls	2.0	5.8	3.65	145
2	Old Burlington Dam	-	6.0	6.00	288
3	Jim Falls	1.5	7.0	9.60	500
4	Winter Dam	7.5	-	-	3 000
5	Blue Marsh	7.6	6.4	14.60	1 300
6	New Kernsville Dam	7.0	-	15.00	500
7	La Maignannerie	-	4.5	2.25	80
8	'Saint Jory'	-	6.0	2.6	120
9	La Calilade	-	4.1	3.5	140
10	Marcillac	-	4.1	3.0	122
11	Pocano Lake	1.0	2x2.0	7.0	286
12	Columbia Mills	2.0	1x1.0	5.2	425
13	Brantford	2.0	4.0	4.0	110
14	Ontelaunee Dam (Unit)	2.3	9.0	11.0	550
15	Lac Courte Oreilles	6.40	1 500	9.15	3 450
16	Pine Grove Dam	3.96	175	11.89	478
17	Schaads Reservoir	2.67	42	29.57	240
18	Second Broad River	2.19	246	6.40	288
19	Superior Dam	2.74	567	4.27	570
20	Tierckenkill Falls	0.94	11.9	30.49	70
21	Traicao	6.06	8 333	6.49	8 570

Fig. 1

PROTOTYPE SYPHON - HYDRO INSTALLATIONS

2 - Research Work 1984-1986

Although most conventional hydro installations are site specific, syphon hydro lends itself to the possibility of a standardized "off-the-shelf" design. The principal design considerations for syphon hydro are the suction lift, priming, intake configuration and penstock design.

From these earlier studies by Acres, it was found that the hydraulics of a syphon installation, namely, the suction lift and intake configuration, including submergence, play a major role in optimizing the efficiency of a system.

Most major installations usually include a physical hydraulic model study in the design phase. Apparently, however, not one of the more recent syphon installations seen in Figure 1 used a model as a design tool. Because of their small size, reasonably conservative design concepts were adopted.

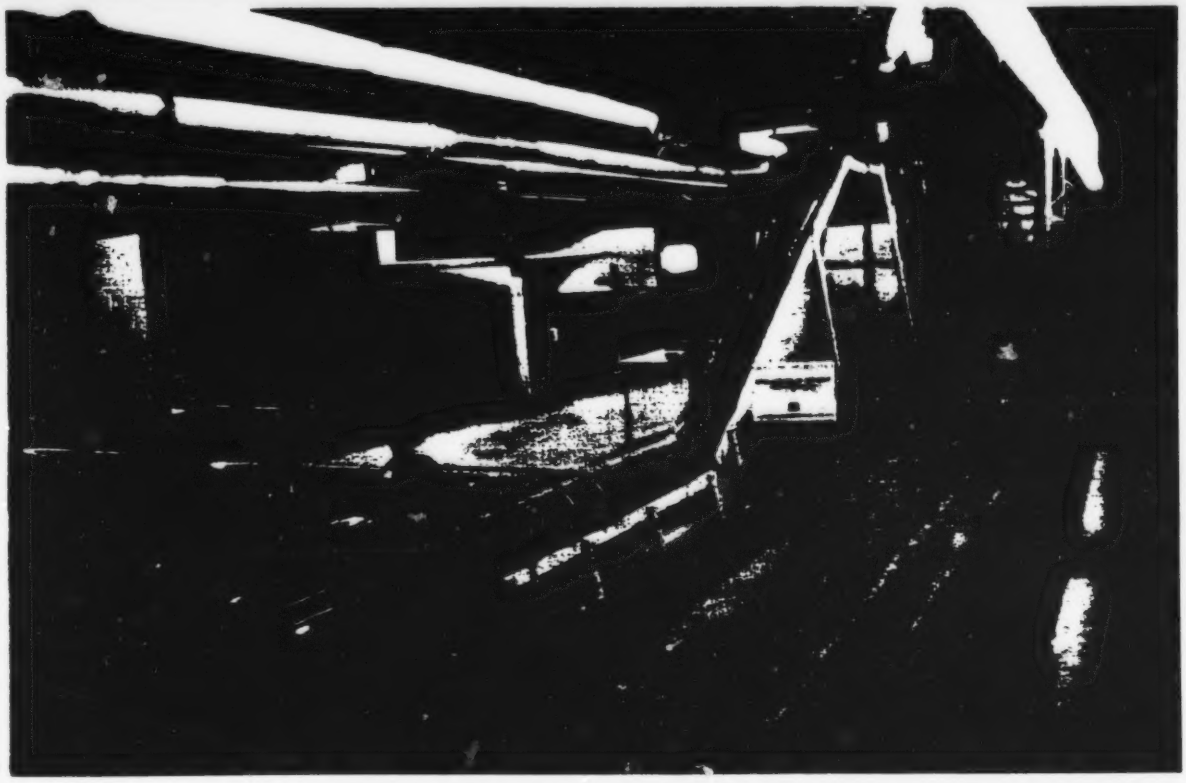
The first technical study carried out under the Energy Mines and Resources, Research and Development program to investigate syphon hydro began in 1986.

The literature review for this study included the analysis of site characteristics and several relevant laboratory research studies to summarize performance information relative to intake geometry, submergence, transients and air entrainment. Principal conclusions from this work showed that

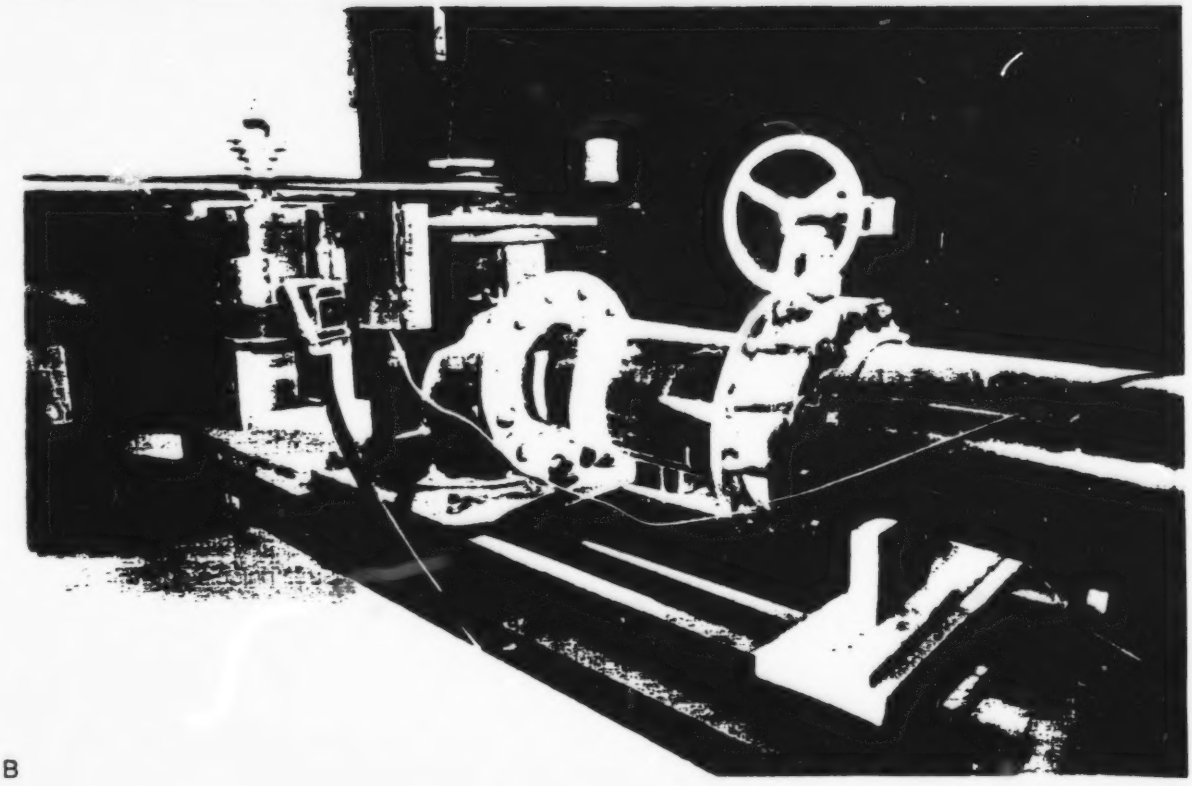
- experimental and theoretical information on submergence was lacking
- an improved submergence criteria was required for syphon intakes and
- the use of small-scale models has led to wide discrepancies in interpreting prototype vortex activity.

A laboratory study was therefore carried out at model length scales of 1:2 and 1:3 with model discharges and heads corresponding to typical micro hydro sites.

Figure 2a shows the model syphon hydro laboratory setup. The primary objective of the study was to investigate intake geometry, submergence and the performance of the model syphon



A



B

Fig. 2

LABORATORY SYPHON - HYDRO INSTALLATION

installation by measuring the power output of a turbine generator subjected to poor intake conditions.

The turbine unit (Figure 2b) was an Ingersoll-Rand, single-stage, vertical turbine pump equipped with a belt-driven, 1.5-hp Westinghouse AC induction generator. Immediately downstream of the intake leg of the syphon, a sloping 45-deg face was installed to simulate a typical upstream sloping face of a small dam structure.

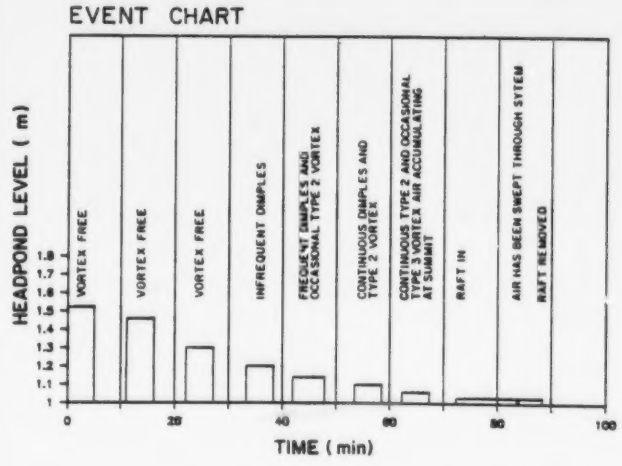
Hydraulic, mechanical and electrical data, were recorded with a data logger, and stored on tape for later computer analysis.

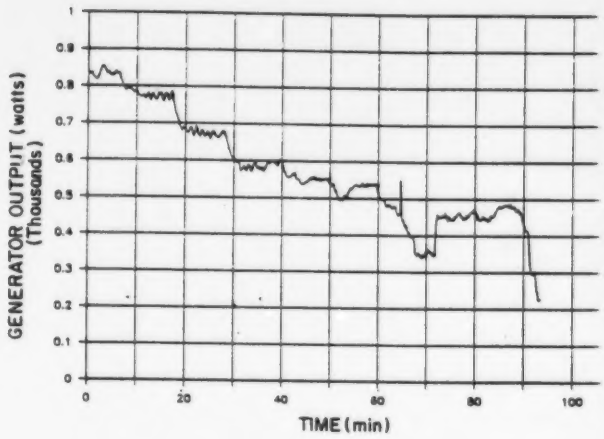
A testing program was implemented to examine two basic intake configurations—the circular and rectangular bellmouth—and to assess quantitatively their response to a range of submergences by monitoring the power output.

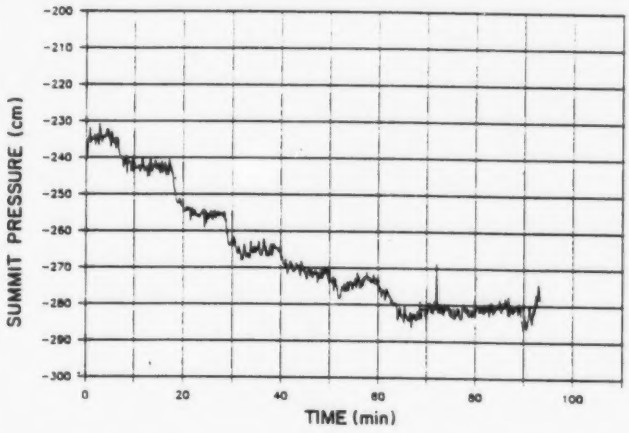
Figure 3 gives an example of the monitored data for a series of tests with the system initially operating at maximum turbine discharge. In these tests, the loss in power output for changes in submergence was determined for a circular bellmouth. The event chart in the first box of Figure 3 gives the vortex activity due to the lowering the water level, thereby reducing the intake submergence. The variations in other parameters resulting from these water level changes can be seen in the remaining five boxes. The effect of introducing a typical vortex suppressor in the form of a surface raft is clearly evident at 70 minutes into the test.

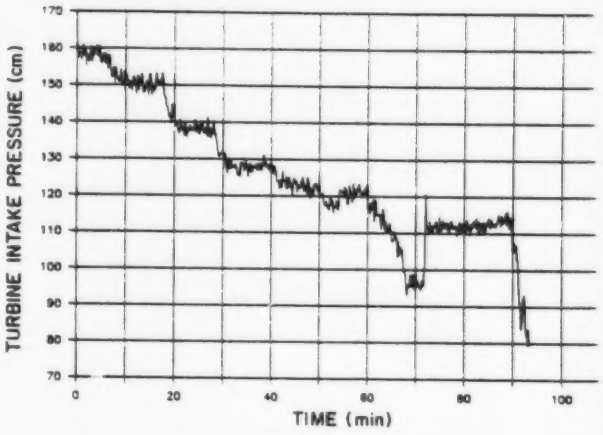
Observations at the crown of the syphon constructed of clear acrylic plastic gave an insight into the behavior of air in the installation. Lowering of the water level induced the formation of vortices, and air began to collect at the crown. Depending on the velocity in the pipe, the air would either be swept downstream through the turbine or grow into a large bubble at the crown until a hydraulic jump formed in the downstream leg of the penstock. Figure 4 shows the effect of this progressive air accumulation at the crown.

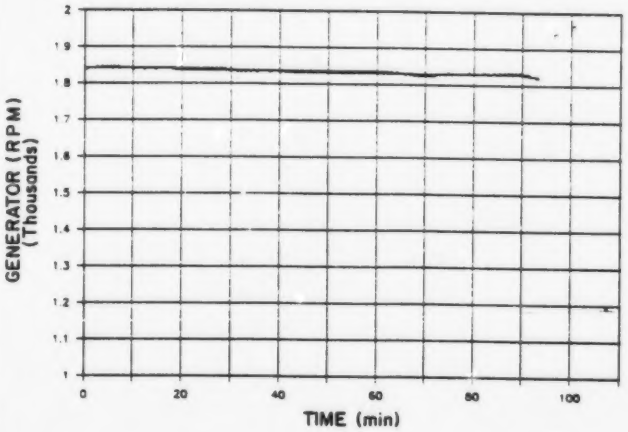
This appears to be the first time that an investigation has been made to quantitatively determine the effect of intake conditions and associated air entrainment on the power output in a syphon installation.


EVENT CHART
HEADPOND LEVEL (m)
VORTEX FREE
VORTEX FREE
VORTEX FREE
INFREQUENT DIMPLES
FREQUENT DIMPLES AND OCCASSONAL TYPE 2 VORTEX
CONTINUOUS DIMPLES AND TYPE 2 VORTEX
CONTINUOUS TYPE 2 AND OCCASIONAL TYPE 3 VORTEX AIR ACCUMULATING AT SUMMIT
RAFT IN
AIR HAS BEEN SWEPT THROUGH SYTEM
RAFT REMOVED
TIME (min)









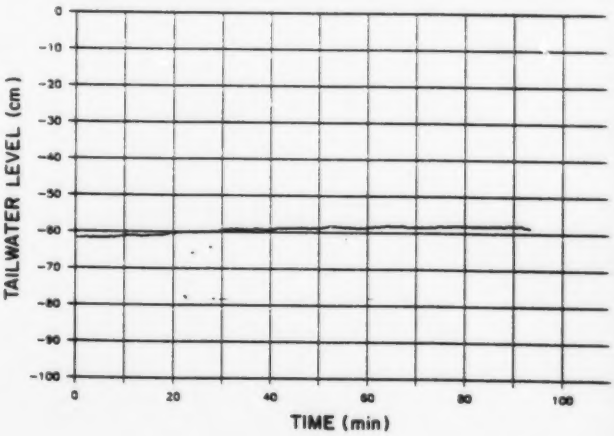


Fig. 3

POWER RUN B1

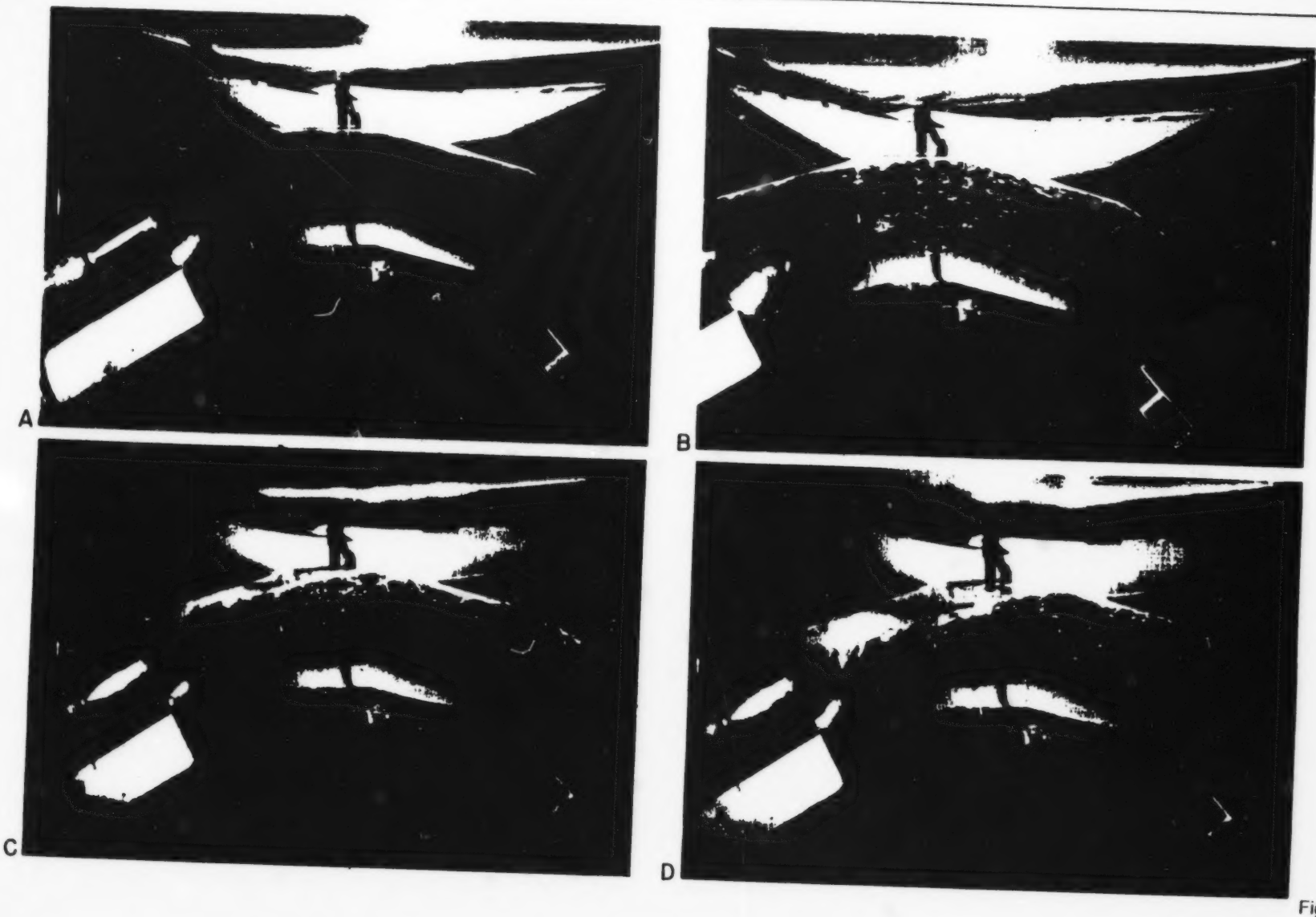


Fig. 4

STAGES OF AIR ACCUMULATION AT SUMMIT

ACRES

Submergence Tests

As pointed out earlier, submergence design criteria has evolved from past research work and field observations. Almost all of this work has been carried out using conventional intakes, either in the horizontal or vertical attitudes. Certainly there is no evidence of work being carried out using either small pump or syphon installations with intakes on a sloping face.

A further series of tests were therefore run to examine the submergence for a syphon intake on a sloping face. In these particular tests, none of the parameters recorded in the power runs were monitored. These were replaced with careful observations of the vortex behavior at the intake for each water level.

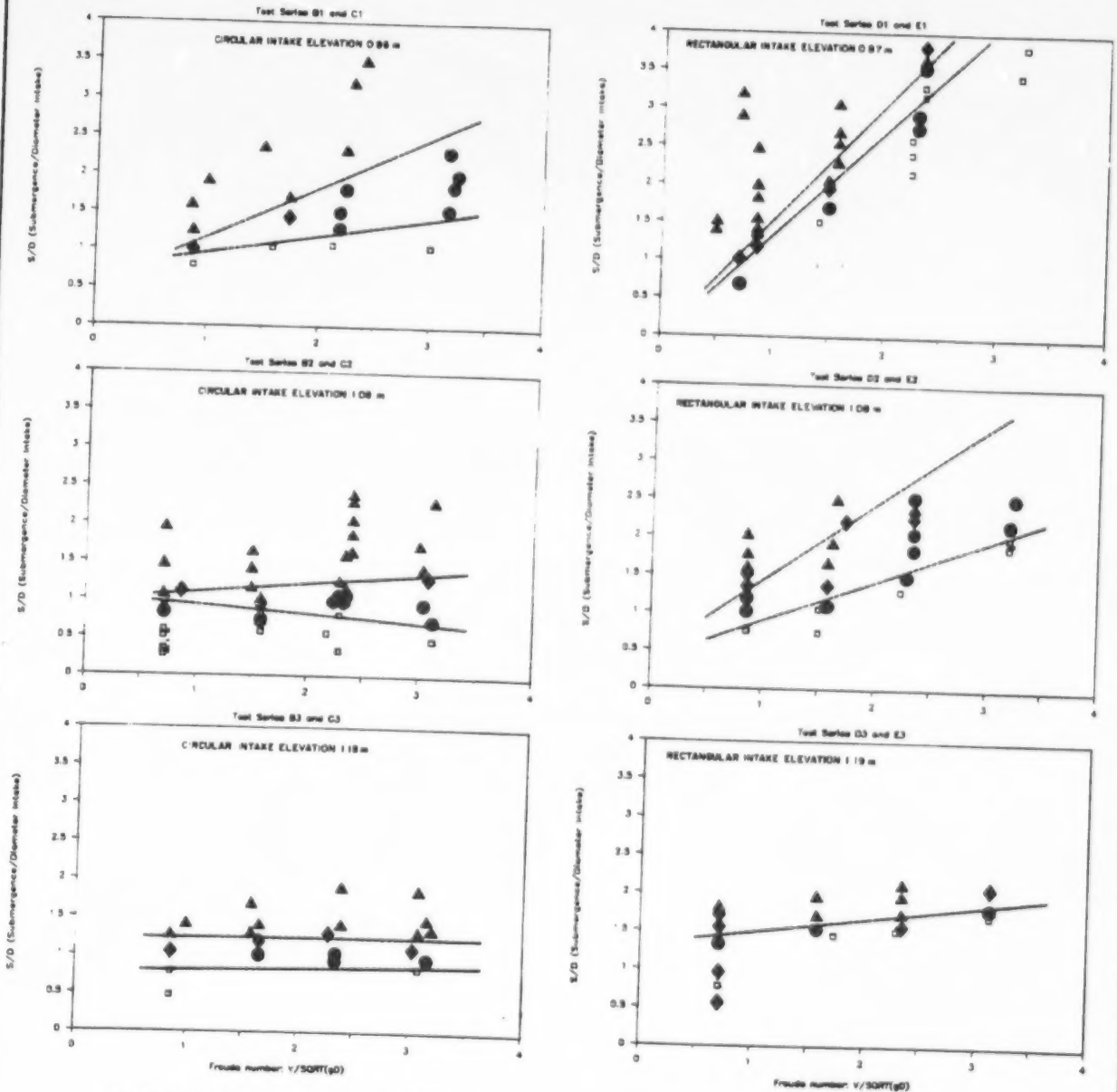
Figure 5 shows the plots of the submergence ratio S/D against the intake Froude number for the three different elevations of the two intake types. A division has been drawn between those observations termed 'vortex-free' and those with continuous vortex activity. The plots for both bellmouth shapes show a definite pattern in that as the intake is raised, the critical S/D ratio is reduced at high Froude numbers or, in other words, a greater submergence is required for the lower intake elevation. Principal conclusions reached from this second study for EM&R are as follows.

(a) Air entrainment played a significant role in reducing the power output of a turbine.

(b) Attaching a syphon intake to a sloping, upstream face of a dam is a practical and inexpensive method of installing a microhydro system.

(c) The circular bellmouth intake required less submergence than the rectangular intake for the same Froude number.

(d) For the sloping structure face and range of water levels tested, less submergence was required for the highest elevation of the three intake positions tested. This appeared to result from the shorter distance to the sloping face which causes disturbances on the water surface that dampened vortex formation.


CIRCULAR INTAKE ELEVATION 0.86 m
RECTANGULAR INTAKE ELEVATION 0.87 m
CIRCULAR INTAKE ELEVATION 1.09 m
RECTANGULAR INTAKE ELEVATION 1.09 m
CIRCULAR INTAKE ELEVATION 1.19 m
RECTANGULAR INTAKE ELEVATION 1.19 m
S/D (Submergence/Diameter Intake)
Froude number V/SQRT(gD)

SUBMERGENCE RUNS B AND C

SUBMERGENCE RUNS D AND E

□ Continuous Vortices ● Continuous Dimples ◆ Dimples ▲ Vortex Free

Fig. 5

SUBMERGENCE RATIO VS. INTAKE FROUDE NUMBER

Research Work 1986-1988

A further study, carried out in 1986, was to investigate a specific conventional intake configuration with respect to

- submergence
- intake geometry
- mitigative measures to permit the intake to operate at a submergence below the normally accepted minimum.

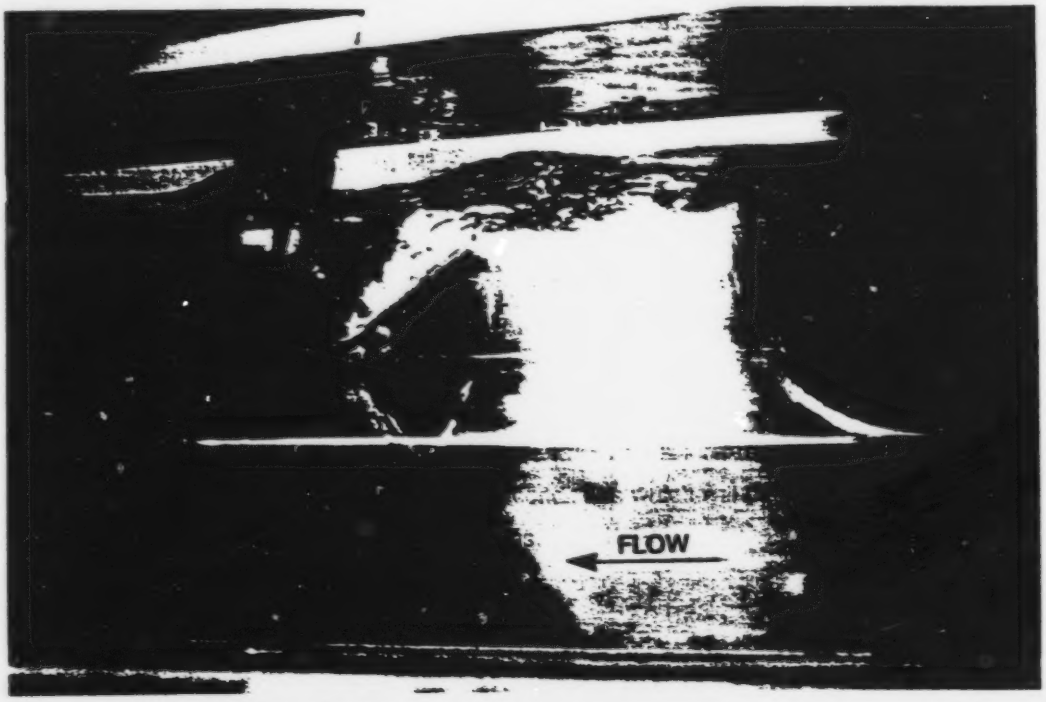
Using a scale relationship of 1:5, the testing program consisted of evaluating the performance of several vortex suppression devices while varying the following test conditions.

- approach channel width
- bottom clearance between the intake face and the channel floor
- channel water depths

The following types of vortex suppression devices were examined.

- hydrodynamically-shaped nose
- raft
- rear wall
- hooded intake
- channel geometry

Figure 6a shows the typical vortex patterns that would occur for this particular intake in the absence of any suppression device. A proto-type discharge of 12 m3/s was represented in the model with water depths equivalent to 4.3 m. The size of the intake was 3.5 m long and 1.26 m wide.



A) SEVERE VORTEX ACTIVITY
SUBMERGENCE = 0.78m

B) SUBMERGED VORTEX ACTIVITY
SUBMERGENCE = 2.31m

Fig. 6

VORTEX PATTERNS WITHOUT SUPPRESION DEVICE

Figure 6b shows that, despite a very conservative submergence, a submerged vortex formed when the approach channel was narrowed. At this stage of the testing program, some preliminary conclusions were formed, as follows.

- The geometry of the approach channel had a significant effect on whether or not a free surface vortex formed.

- To an extent high approach velocities reduce rotational surface flow and associated vorticity.

- For the same velocity, a narrow channel free of surface vortices may induce the formation of submerged vortices.

- Squared edged front and rear intake shapes caused separation.

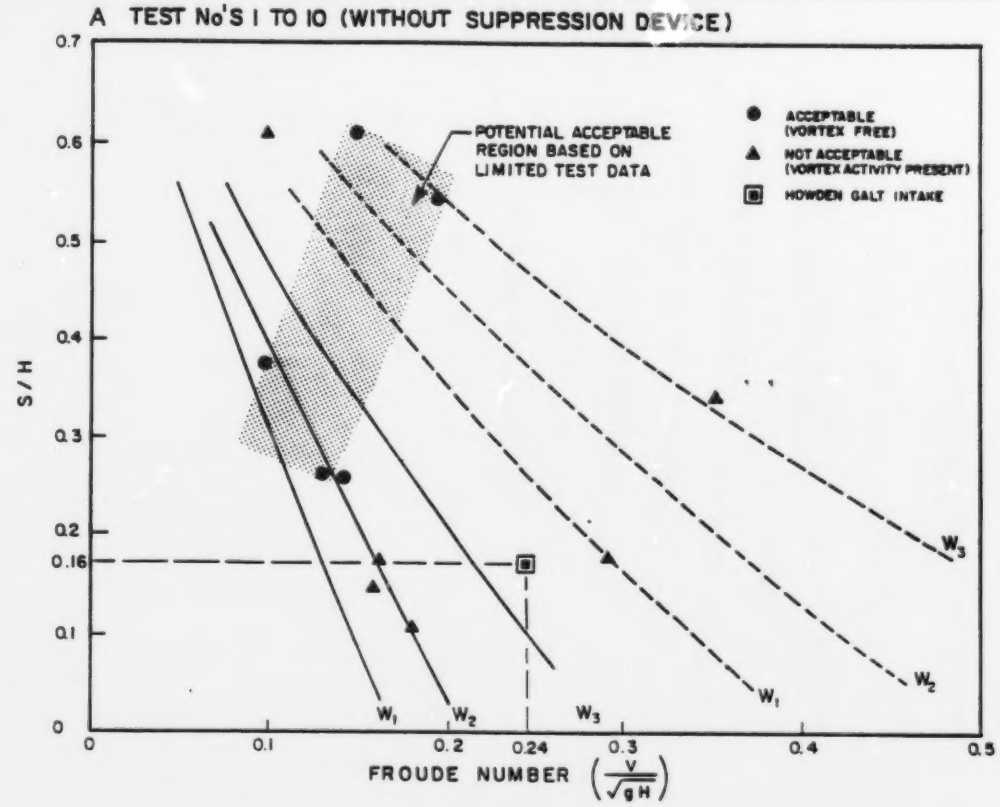
Figure 7 shows the relationship between the ratio of submergence and channel depth versus the approach Froude number. Figure 7a indicates whether a suppression device is deemed necessary or not to reduce vortex activity. The curves are for a constant discharge of 12 m3/s.

Figure 7b shows the same relationship but with different types of suppression devices. A total number of 51 tests using various hooded intake configurations, side plates and full rear walls, were utilized.

Figures 8a and 8b show the dramatic effects of the approach geometry on a modified hooded intake.

Further data analysis from these tests indicated a potential region of acceptable vortex behavior as a function of the intake submergence and the approach channel Froude number. The study showed that the critical submergence increased as the approach channel Froude number increased.

Therefore, a relationship exists between the conditions in the approach channel, the geometry of the intake, the clearance between the intake and the channel floor and the presence of vortex activity at the intake. In addition, the approach velocity can influence the strength of either surface or submerged vortices.



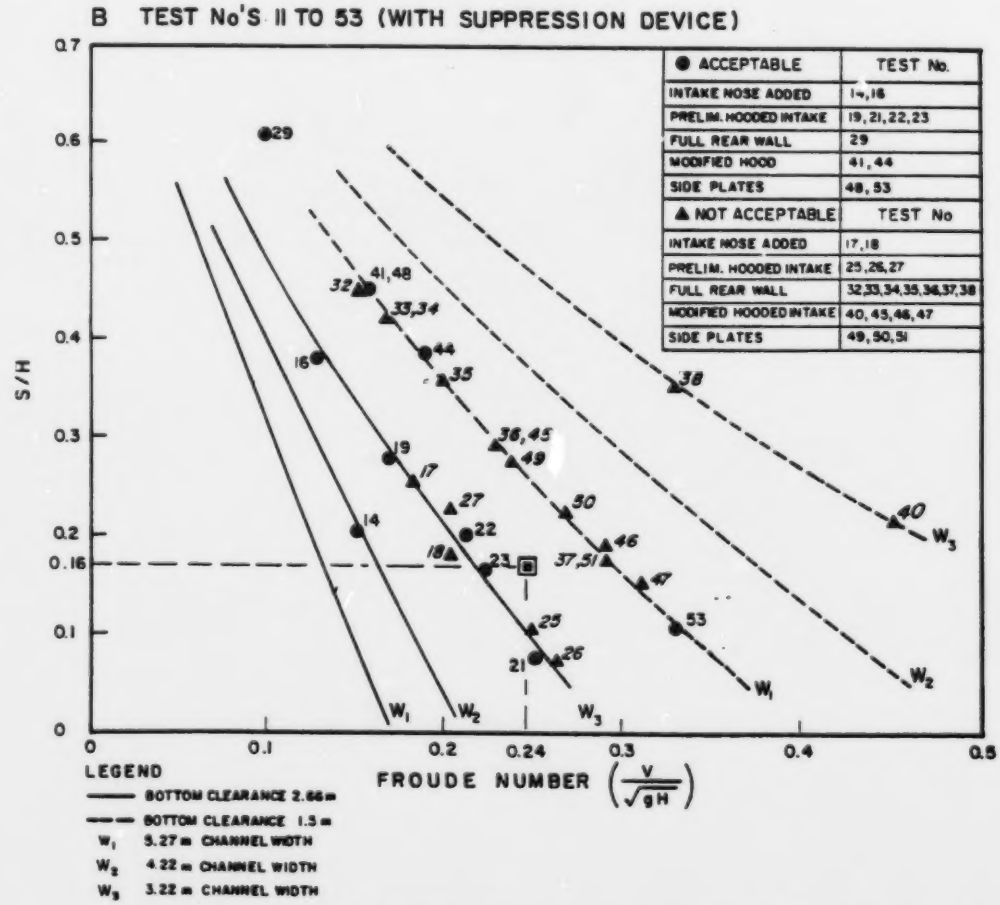
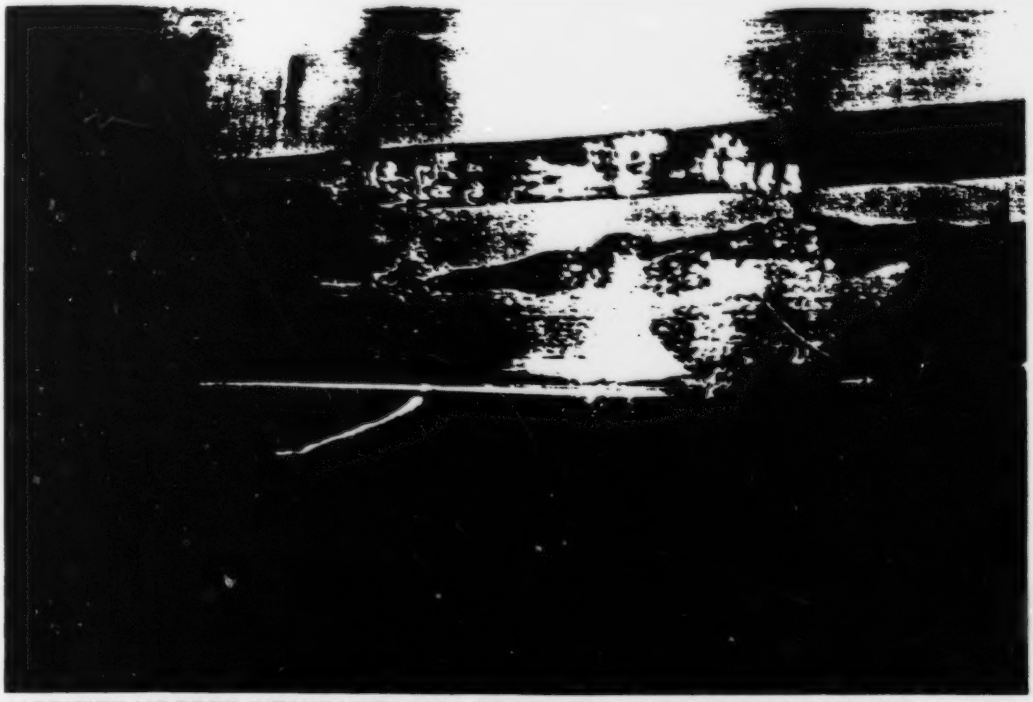

B TEST No'S II TO 53 (WITH SUPPRESSION DEVICE)
ACCEPTABLE | TEST No.
INTAKE NOSE ADDED | 14,16
PRELIM. HOODED INTAKE | 19,21,22,23
FULL REAR WALL | 29
MODIFIED HOOD | 41,44
SIDE PLATES | 48,53
NOT ACCEPTABLE | TEST No
INTAKE NOSE ADDED | 17,18
PRELIM. HOODED INTAKE | 25,26,27
FULL REAR WALL | 32,33,34,35,36,37,38
MODIFIED HOODED INTAKE | 40,45,46,47
SIDE PLATES | 49,50,51
S/H
FROUDE NUMBER (V/√gH)
LEGEND
BOTTOM CLEARANCE 2.66 m
BOTTOM CLEARANCE 1.5 m
W1 5.27 m CHANNEL WIDTH
W2 4.22 m CHANNEL WIDTH
W3 3.22 m CHANNEL WIDTH

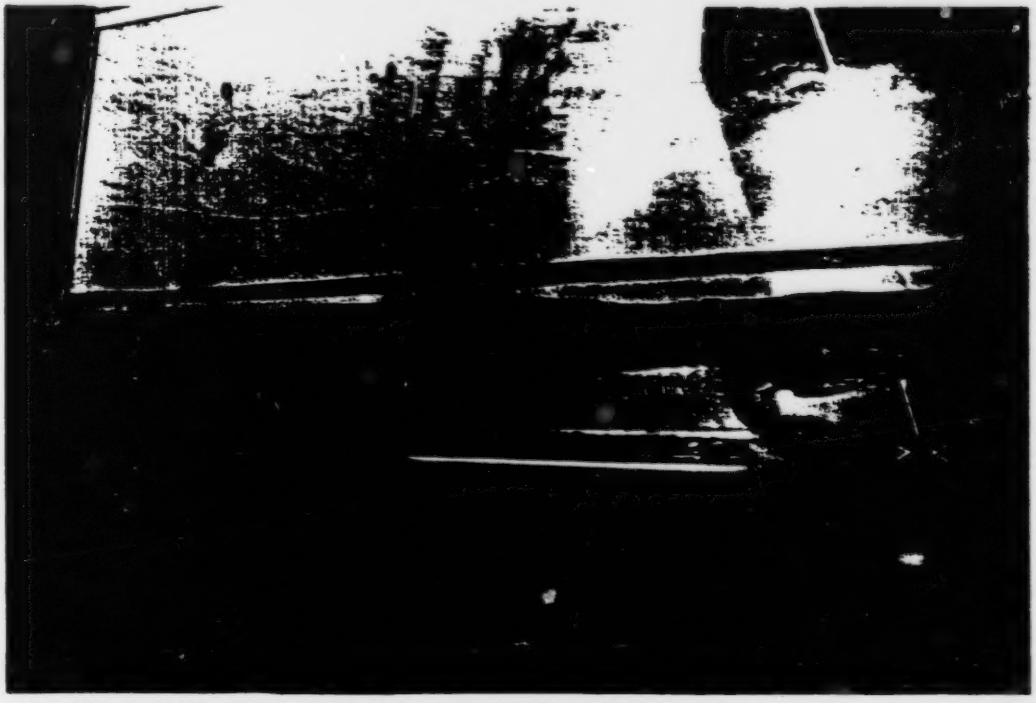
Fig. 7

RELATIONSHIP BETWEEN S/H AND APPROACH FROUDE NUMBER



A

MODIFIED HOODED INTAKE WITH FULL REAR WALL AND NARROW CHANNEL
SUBMERGED VORTEX AND FREE SURFACE VORTEX FORMATION
SUBMERGENCE = 0.41m



B

HOODED INTAKE, FULL REAR WALL AND WIDE CHANNEL
SUBMERGENCE = 0.36m

Fig. 8

EFFECT OF APPROACH GEOMETRY ON HOODED INTAKE

Continued Research Work in Hand

During 1989 further work in association with the Renewable Energy Branch of the Department of Energy, Mines and Resources will further consolidate the previous research and seek to develop a practical set of design guidelines.

The potential region of acceptable vortex behavior will be reexamined further because of its impact on the design of small syphon hydro in- takes. Furthermore, the use of a longer flume will permit the modeling of nonuniform approach conditions which will be more useful in practical applications considering prototype flow patterns.

List of References

Acres International Limited, **Evaluation of Syphon Performance, Phases I, II and III Extension**, 1986-1988.

Acres International Incorporated, **Report on Siphon Penstocks for Hydroelectric Projects**, September 1988.

Acres International Incorporated, **Cost and Design Study of Modular Small Hydro Projects**, Volume 4, Siphon Penstock Model Test Report, June 1984.

FitzPatrick, J. B., **Evaluation of Syphon Performance**, Proc., Small Hydro '87, Vancouver, BC, March 24-27.

Western Canada Hydraulic Laboratories, Draft Report - **Hydraulic Testing of Multiple Syphon Generator Intakes**, June 1988.